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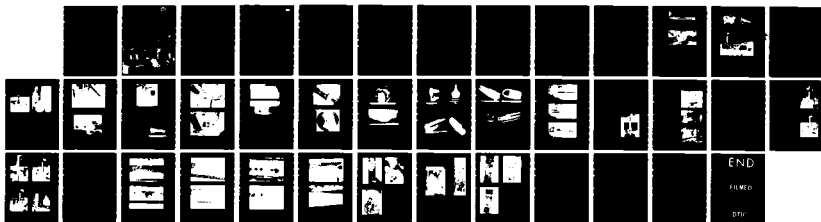
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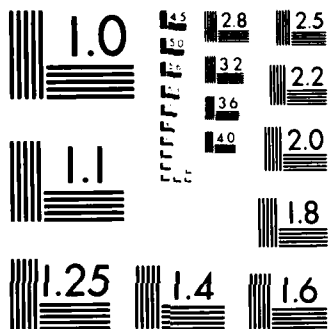
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Prototype drill for core sampling fine-grained perennially frozen ground

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January 1985

Prototype drill for core sampling fine-grained perennially frozen ground

Bruce E. Brockett and Daniel E. Lawson

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number) An inexpensive drill has been modified to provide researchers with the ability to auger an open hole or to acquire continuous, undisturbed 76-mm-diam core samples of a variety of perennially frozen materials that are suitable for chemical and petrographic analysis. It was developed by field testing in support of research from 1980 to 1983. Operation of the drill is based mainly on using a minimum of power to cut through frozen ground with tungsten carbide cutters on a CRREL coring auger. The ice content, temperature and grain size of the frozen sediments are important variables determining the sampling depth. Perennially frozen sediments with temperatures in the range of -0.5°C to -8.5°C have been continuously cored with this drill. Drilling and sampling are most efficiently		

20. Abstract (cont'd).

conducted when ambient air temperatures are below freezing and the active layer is frozen. The self-contained light-weight drill is readily transportable off-road by helicopter or tracked vehicle, or by towing over roads. It is locally self-mobile by use of a winch. Total cost of the drill and modifications is estimated at approximately \$10,000.

PREFACE

This report was written by Bruce E. Brockett, Physical Science Technician, and Dr. Daniel E. Lawson, Research Physical Scientist, of the Earth Sciences Branch, Research Division, U.S. Army Cold Regions Research and Engineering Laboratory. Field studies were primarily funded by the U.S. Geological Survey, Office of the National Petroleum Reserve-Alaska (NPRA) and supplemented by funding from the Office of the Chief of Engineers, through various military and civil works projects.

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A PROTOTYPE DRILL FOR CORE SAMPLING FINE-GRAINED PERENNIALY FROZEN GROUND

Bruce E. Brockett and Daniel E. Lawson

INTRODUCTION

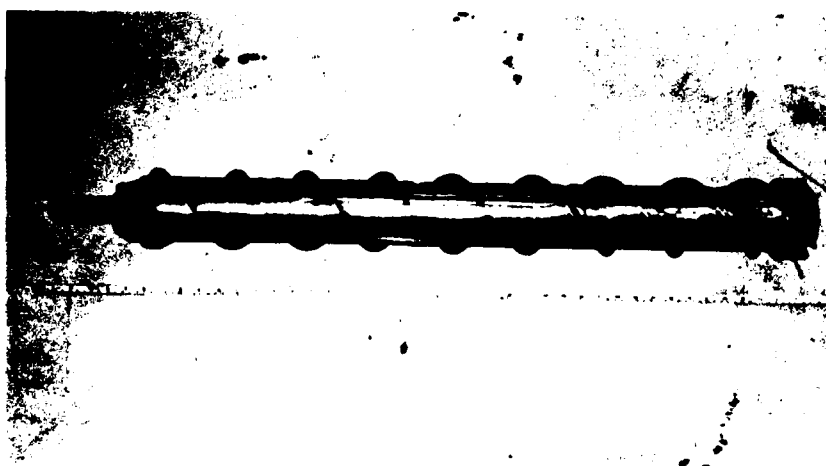
As part of a research project on the environmental effects of former exploratory drilling operations in parts of northern Alaska (Lawson et al. 1978, Lawson and Brown 1979, Lawson 1982), studies were begun in 1977 on the origins and characteristics of the perennially frozen ground, or permafrost, which underlies this region. This study required subsurface geological information and undisturbed samples of the perennially frozen sediments that overlie frozen bedrock at depths ranging from 10 to 30 m.

It became clear after our initial efforts in obtaining subsurface information that existing equipment and techniques were not suitable for researchers inexperienced in drilling who wished to core sample below depths of around 2.0 m. Therefore, drawing from previous experiences (e.g. Sellmann and Brown 1965, Davis and Kitze 1967), Mellor and Sellmann 1975, Sellmann et al. 1976, Nixon 1977) we conducted a subsurface sampling program employing professional drillers and equipment (Lawson and Brockett 1980). These drillers used a Mayhew 200 rotary drill rig with chilled compressed air for circulation and periodically sampled the permafrost at designated depths with a modified Shelby tube. While this operation defined the basic character of the perennially frozen sediments above the bedrock, we were not satisfied with the quality or quantity of the core samples. Each sample was heavily disturbed by the modified Shelby tube and stress-fractured by the torque generated by the drill; thus they were not entirely useful for laboratory analyses. Further, the field costs of this operation, including several trips by helicopter to transport equipment and personnel between each drill site, were quite high.

Therefore in late 1979, we evaluated equipment and techniques that were developed specifically for augering or coring permafrost, or for general use in near-surface, frozen materials. In making this evaluation, we were seeking a drill that could 1) auger a shallow open hole and continuously core to depths of 20 to 30 m, 2) obtain core samples of materials with different compositions that were as unstressed and undisturbed as possible, and 3) be cost-effectively transported into and about remote, roadless regions without significant disturbance to the vegetation and permafrost. In addition, we were seeking a low-cost drill system that could be operated safely and successfully by research personnel with little or no drilling experience.

We were also advised that the CRREL ice coring auger referred to in this report as the "coring auger" (Fig. 1) (Ueda et al. 1975) could obtain high quality, basically undisturbed cores of fine-grained, perennially frozen materials, and we selected it as our sampling tool. A suitable power unit, however, had not been adapted to this core barrel to meet our requirements. Specifications for the power unit were therefore based upon the requirements for optimizing performance of the corer, and based upon our review of equipment and techniques, a portable, lightweight drill was adapted for use with this coring auger.

Because the primary goal for our efforts was to obtain undisturbed core samples of permafrost in support of on-going research and not to fabricate a totally new drill, we did not undertake a controlled, systematic design and testing program. The configuration of the drill, as described in this report, has resulted from field experiences during the period of 1980 to 1983, and subsequent modi-



a. Coring auger.



b. Adjustable cutters and head of core barrel.

Figure 1. A lightweight, chromed 76-mm-diam CRREL coring auger modified for use in fine-grained, perennially frozen materials.

fications to the original configuration that resulted from those field experiences.

In this report, we describe the development and configuration of the prototype drill for continuous undisturbed core sampling of permafrost. In addition, we discuss pertinent aspects of the drill's performance and limitations.

BACKGROUND ON DEVELOPMENT

Since the coring auger was developed and modified for use in fine-grained frozen materials (Ueda et al. 1975), locating a power unit suitable for sampling permafrost at depths greater than a few meters has proven difficult. In addition to re-

quiring a unit powerful enough to drive the coring auger in a variety of materials without producing a torque that would overcome the strength of the operator(s), the unit had to be portable and lightweight for use in remote regions. Some of the hand-held units that have been adapted to the coring auger were described by Ueda et al. (1975).

One power unit commonly used is the Haynes Earth Drill model 500 or "Little Beaver" (Fig. 2). This unit is powered by a 5.0-hp Briggs and Stratton four-cycle engine. Power is transmitted through a flexible shaft to a centrifugal clutch and 10:1 gear reduction transmission. The model 500 weighs approximately 45 kg. Including sampling accessories, the weight is approximately 136 kg.

The major problem that we encountered with



Figure 2. Haynes Earth Drill Model 500 or "Little Beaver" with CRREL coring auger.

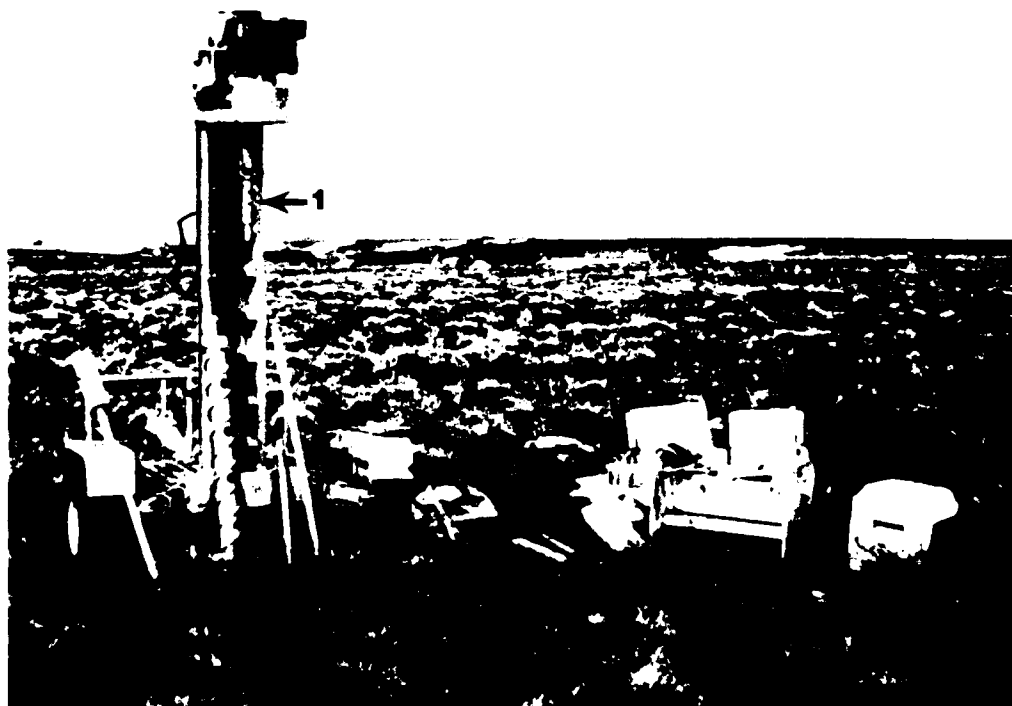


Figure 3. General Model 550 Dig-R-Mobile drill with hex-to-round adapter (1), coring auger (2), and core catcher (3) as used in Alaska in 1980.

this unit was sticking of the core barrel in the hole. The core barrel often stuck when thawed or partially thawed zones were encountered. In these zones, cuttings built up on the flights, jamming between the core barrel and hole wall. As the resistance to rotation increased, the governed motor increased power to compensate for this resistance, thereby increasing the torque beyond that which

the operator could physically control. After rotation stopped the barrel froze to the hole walls and could not be pulled out. We had difficulty in obtaining core samples below 2.0-m depth and found the unit too cumbersome for use over tundra vegetation.

On the basis of our research requirements as stated previously, we selected a small, trailer-

mounted post hole auger, the General Model 550 Dig-R-Mobile for use with the coring auger. This drill has the simplicity of operation, power, ease of mobility and feed control necessary for deeper coring. This unit (Fig. 3) uses a 7-hp Tecumseh engine, and an enclosed spur gear reduction transmission that produces 381 N-m (281 ft-lb) of torque and a maximum of 144 rpm. The power unit is mounted in a cradle for vertical travel on a mast. Vertical travel and feed is controlled by a 40-mm (16-in.) hand-operated wheel that raises and lowers the cradle and drill head through a double reduction chain drive. The mast tilts 10° on lateral axis and 15° on longitudinal axis for adjusting the mast to a near vertical position. The basic drill weighs approximately 318 kg.

In order to evaluate the performance of this power unit with the coring auger, we rented a Model 550 and field tested it while conducting research during May and June of 1980 in northern Alaska (Fig. 3). The only modification made to the rental unit was welding a hook on the top of the mast for sling transport by a helicopter. An adapter was fabricated to connect the CRREL corer and its extension rods to the output shaft.

We were successful in recovering high quality cores of ice-rich and ice-poor frozen sand or silt and ice wedge ice. Sixty holes were continuously cored to an average depth of 2.5 m and a maximum depth of 5.3 m. Depths of sampling were primarily limited by the material types, difficulties in pulling the core barrel and rod extensions by hand below 4 m, and a conservative approach for these first field tests to ensure that research objectives were met.

Nevertheless, the field test demonstrated that the model 550 with certain modifications could provide a suitable base unit for core sampling continuously to depths exceeding 5.3 m. Research needs required samples to depths of 20 m and we felt it highly likely that, with modification, 20 m could be attained with the model 550.

Two basic assumptions were made before implementing any modifications to the model 550:

1. The CRREL coring auger equipped with tungsten carbide cutters is suited for core sampling ice-rich, fine-grained frozen sediment and produces a clean hole that eliminates the need for drilling fluid.

2. The only two factors that govern the penetration rate of the coring auger are the depth of cut of the carbide cutting inserts and the revolutions per minute of the core barrel; thus, excessive downward pressure or high torque are unnecessary.

Modifications described in the next section were based upon the 1980 field tests and subsequent field tests of modified versions of the drill rig in 1981, 1982 and 1983.

DRILL DEVELOPMENT AND CONFIGURATION

Equipment

The following major pieces of equipment were purchased to develop the drill in its present configuration:

1. Model 550 Dig-R-Mobile from the General Equipment Co., Owatonna, Minnesota.
2. Implement jacks, 900-kg capacity, with 0.38-m travel (2 ea.).
3. Implement jack, 900-kg capacity, 0.25-m travel (1 ea.).
4. Implement jack mounts (3 ea.).
5. Goodyear Xtra-trac Terra tires, 31 × 15.50, 4-ply tubeless nylon, mounted on rims with wheel studs and lug nuts.
6. Portable winch, gasoline engine driven, with a 6:1 gear reduction system, and 90 m of 6.35-mm (¼-in.) wire cable.
7. Constant speed electric winch, reversible, 112-V a.c., with 60 m of 4.76-mm (⅜-in.)-diam galvanized aircraft cable.
8. Portable generator, 3-kW, 120-V, 1800 rpm.
9. Fabricated metal skis (3) of 6.35-mm-thick aluminum channel of 0.305-m width and 1.2-m length.
10. Continuous flight auger, 57-mm-diameter, 1 m long (designed by A. Kovacs).

Modifications

Base unit

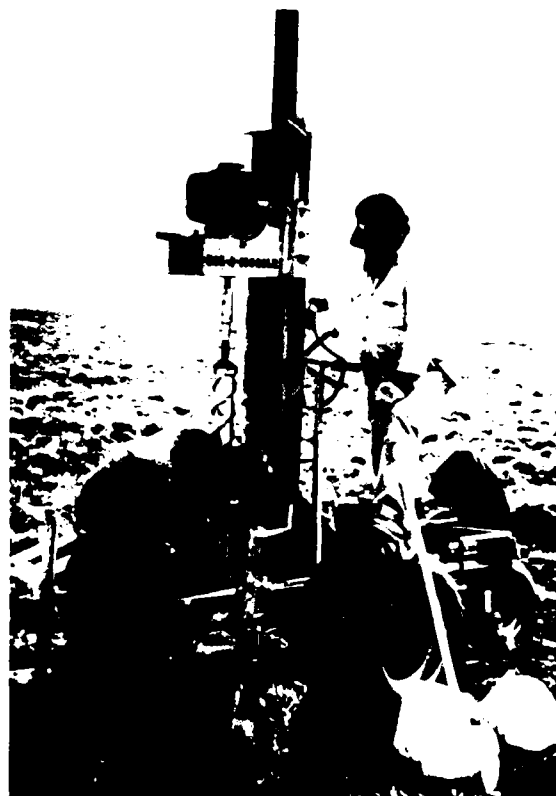
A hinged mast extension is added to the Dig-R-Mobile using a 1.2-m-long, 0.1 × 0.1-m steel tube (Fig. 4). Two cable rollers are made from 19-mm aluminum plate and positioned so that the winch cable will hang centered over the hole. A standoff bracket is attached to the top of the extension for the purpose of locking the extension to the mast when in the down or transport position (Fig. 5). The extension is installed or removed by inserting or pulling the hinge pin. Initially the extension was locked in the upright position by a snap clamp mounted on the rear of the mast; this clamp was eliminated after the first field season due to its tendency to vibrate open. The extension is now bolted to the top of the mast with 16-mm bolts and

Only certain important aspects of coring are briefly described below.

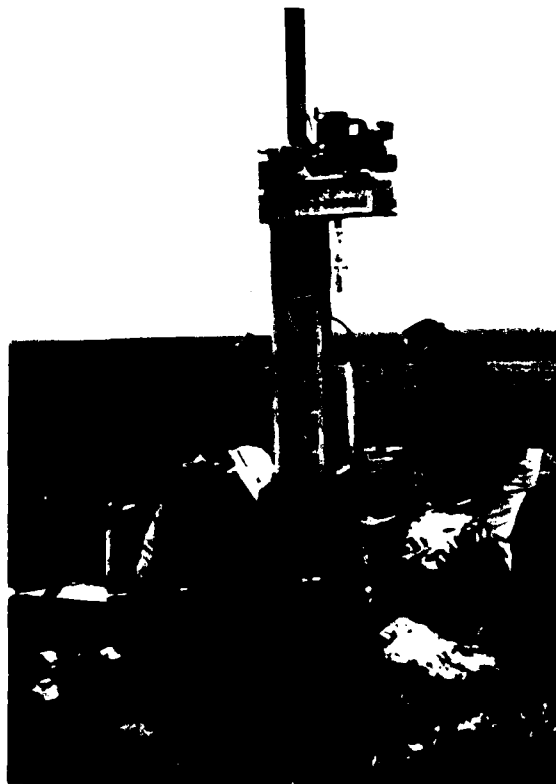
The basic procedure is as follows. After establishing a vertical pilot hole, the coring auger is attached to a 0.5-m length of drill rod and the output shaft, and coring is begun (Fig. 23a). As the hole progressively deepens, lengths of drill rod are added (Fig. 23b). After each core is cut, the motor cradle is swung aside and the rod and barrel are raised by the electric winch. The rod is removed using the pin and plate system. The plate is slipped around the rod and the pin inserted through the hole in the rod (Fig. 10). The drill string is lowered until all weight is suspended from the pin that rests on the plate. Sections of rod are disconnected, removed from the winch cable, and set aside (Fig. 23c, d). The cable is reattached to the top of the remaining drill rod. The suspended drill string is then raised slightly, the pin and plate removed and the drill string is raised until the next rod-to-rod connection is above the ground surface. The winch cable is kept taut at all times. This process is repeated until the core barrel is retrieved (Fig. 23e, f). When lowering the core barrel back to the bottom of the hole, the addition of sections of rod by using the pin and plate system, as described above, is reversed. These core sampling procedures effectively provide a safe operating environment, as there is never a need for personnel to be near the core hole when the motor is in use and the drill string is rotating. All trips up and down the hole are made without rotation.

The most difficult aspect of using the drill and coring auger is having the patience to maintain a consistent rate and depth of cut. At a depth of 20 m for example, it takes a minimum of 10 minutes to descend the hole, cut a sample, pull the rod and core barrel to the surface and remove the core.

When cutting a core, only seven revolutions of the wheel should be made, as this number of revolutions equals a penetration depth of 0.3 m or one-third the length of the core barrel. This length is critical because for every 0.3 m of core that is cut, 0.6 m of cuttings is collected on the coring auger's flights and within the core barrel. Exceeding this depth of cut or having improperly matched carbides will cause cuttings to accumulate above the flights, where they will be compacted during retrieval, causing the core barrel to jam within the hole and subsequently freeze to the hole walls. The only successful method found to free a jammed and frozen core barrel is by lowering the freezing point of the cuttings and causing them to thaw by pouring antifreeze solution into the hole. Depending on ground temperatures, it can take 12 to 24 hours before the core barrel is freed. Recently we have reduced this time to ½ hour by injecting air from a portable air compressor directly above the



a. Attaching coring auger for core sampling after augering pilot hole in active layer.



b. As hole deepens, drill rod is continually added, with rod stabilizers on rod ends.

Figure 23. Sequential photos of typical operating procedure for continuous coring deep drill holes in northern Alaska in 1981.

roads, the unit can be towed behind vehicles having a 2-in. (50 mm) ball trailer hitch. Off road, we have towed it by tracked vehicle and snowmobile. The modified drill, unassembled, will fit into a small plane (e.g. a Twin Otter).

The drill can be incrementally moved by attaching the winch cable to a fixed object, such as a dead-man, and reeling it in (Fig. 22). When towing through deep snow or large tussocks, we have found that having the winch at the rear of the drill (pulling towards the smaller front tires) adds the advantage of vertically rocking the drill as the winch cable is strained. This rocking motion lifts the front wheels off the surface, momentarily redistributing the weight slightly behind the larger rear tires, and causing the drill to waddle forward.

Precise positioning of the drill with the motor shaft centered over the desired sampling location is relatively easy to do. This positioning can be accomplished by rotating the large tires by hand, pushing from front or rear. The size of the tires provided excellent leverage while minimizing the adverse effects of tundra vegetation in restricting movement.

Typical operating procedures

Augering

Once on site, the drill is positioned over the sampling location. The mast is first coarsely adjusted to a near-vertical orientation by using the mast leveling adjustments. The mast is then leveled using the jacks that have been set on boards to retard sinking into thawed soil or a snow cover. Finally, the wheels are firmly chocked. Drill rod and related equipment are laid out and all sampling equipment is set up about 5 m away from the drill.

If the active layer is unfrozen or surface water is present that will flow into the hole, casing must be used. After removal of the thawed materials by augering, the casing is inserted (Fig. 7). The casing prevents collapse of thawed soil into the upper part of the hole, and retards the flow of water into the hole where it freezes on the hole wall and hinders removal of the core barrel. When the ground is frozen, the use of casing is unnecessary and sampling is initiated at the ground surface.

Augers of 0.15-m diam are usually used to set casing. When augering, we generally operate the drill motor at the maximum speed (144 rpm) although the selected speed will vary for materials of differing composition and temperature. The greater speed aids in clearing the cuttings from the hole. Continuous flight augers are not required in holes

less than 2 m deep if the cuttings can be removed by running the auger up and down the hole periodically while under rotation. We have not found it necessary to use auger slips during our operations. Based on our experiences, operating augers with the universal joint connector between the output shaft and auger flights is recommended.

A continuous flight 57-mm-diam auger equipped with tungsten carbide teeth (Fig. 20a) worked well in ice-rich perennially frozen ground for defining subsurface conditions when core samples were not needed. The open hole produced is clean and uncontaminated. Using this tool, we have augered ice and fine-grained ice-rich frozen sediments to depths of 12 m. These depths are not possible if any gravels or unfrozen materials are encountered.

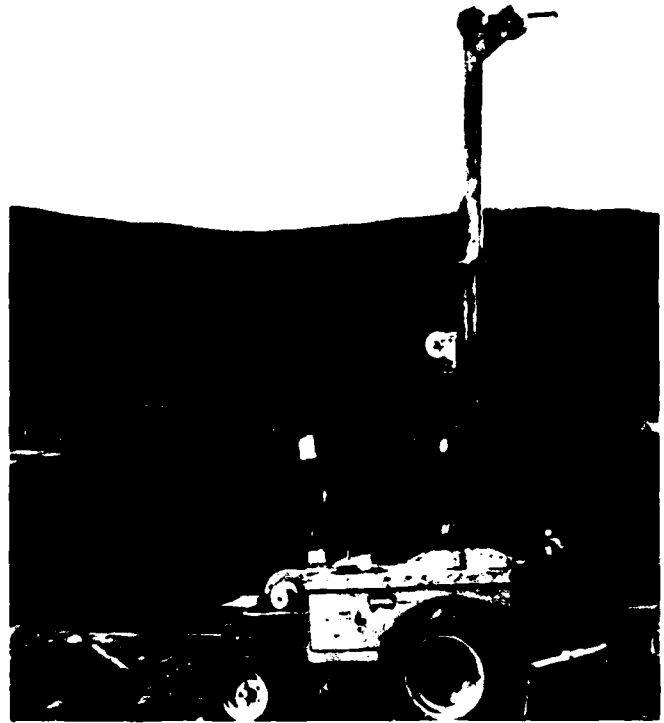
It is important to start with and maintain a vertical hole when augering. If the drill should move, it must be recentered over the hole to avoid excessive strain to the oil seal and bearings of the output shaft. Movement of the drill is a common occurrence especially when larger diameter augers are used. The movement is due to vibration, and even with the jacks set, the lightweight drill can walk off the hole.

Core sampling

The success of cutting and retrieving core samples of undisturbed quality is a function of several factors, perhaps most important of which is understanding and experience with the CRREL coring auger. In our opinion, this coring auger is the best tool now available for extracting undisturbed core samples of fine-grained perennially frozen ground. The core samples are uncontaminated and suitable for both petrographic and chemical analyses. A detailed description of the coring auger and its use, with which an operator should be familiar, is given by Ueda et al. (1975).

Physical factors that can affect the success of extracting high quality core samples include the temperature, ice content and grain size of the perennially frozen materials, the thermal state and moisture content of the active layer, and the ambient temperatures. Operational factors include the rate of penetration, as determined by the angle and depth of cut of the carbides, and rpm of the output shaft. Furthermore, the core barrel and tungsten carbide cutters must be maintained in good condition, with correct radial clearance (I.D. and O.D.) set on the carbide cutters.

Because of the potential variability of these operational and physical factors, we cannot possibly explain every detail of a successful core sampling.



a. Using gas winch mounted on platform with winch cable attached to a dead-man.



b. Using electric winch mounted on front plate, with cable doubled back on itself, front ski mounted under the trailer tongue.



c. Self-winch from a dead-man on the steep slope of Weather Pingo near Prudhoe Bay, Alaska.

Figure 22. Drill movement by self-winch.

Other additions for augering and core sampling include the incorporation of three auger flights with a three-step, six-carbide bit for augering through a coarse-grained active zone and a 76-mm-diam CRREL-style coring auger of 1.5-m length.

Miscellaneous equipment

A storage box was fabricated and mounted on one side of the drill platform. The bottom compartment (Fig. 20a) contains 15, 1-m-long flights of 57.2-mm-diam auger. The middle tray (Fig. 20b) contains a CRREL corer, stabilizers, core retriever, and assorted adapters, while the top tray (Fig. 20c) contains spare cutters and a variety of nuts, bolts, and tools. The cover of the tool box is made from wood and provides electrical ground protection when hooking the drill to a hovering helicopter. Static electric charges can build up during the hookup operation and result in a heavy jolt to the person attaching the choker swivel.

The winch is powered by the 3-kW 120-V generator. A generator with a 1800-rpm specification was selected for arctic operations, because some motors that operate at 3600 rpm have had a tendency to heat unevenly when exposed to arctic winds and mechanical failures have resulted.* This generator was initially mounted on the platform. To reduce the weight of the drill and the noise level, we now position it about 30 m away from the work site.

The following items are also recommended for inclusion in the field supplies:

1. Power pull—1 ea.
2. Handiman type jack—1 ea.
3. Pipe wrenches—2 ea. of 0.46-m (18-in.) length
4. Double-faced hammer of 1.8-kg weight
5. Ratchet set (19 mm)
6. Speed wrench set
7. Mirror
8. Length of chain with safety hooks
9. Spray lubricant
10. Small assortment of wooden blocks and boards
11. Assortment of nuts and bolts
12. Wire brush and assortment of files
13. Emery cloth
14. Casing, 150 mm in diameter
15. Bench grinder

* A. Kovacs, CRREL, personal communication, 1982.

OPERATIONS

Assembly and disassembly

If the drill is shipped completely unassembled and crated, two people can assemble the unit in about 4 hours, provided that an elevated platform, tripod-type overhead structure, or fork lift is available to aid in lifting the mast. An assembly time of less than 1 hour is possible if the base unit is intact. A third person is required if assembly or disassembly is done in the field. No specialized or unique tools are necessary.

We used a total of 14 boxes for shipping the drill, camping equipment and sampling supplies to field locations, with an approximate total weight of 1800 kg and volume of 11 m³. The modified drill and sampling supplies accounted for about 900 kg and 7.4 m³.

Field transport and movement

Transporting the drill to and from remote field sites is typically done by attaching a choker cable and slinging it beneath a helicopter. With the choker cable attached to the top of the mast and the powerhead positioned at the bottom of the mast, the drill is a compact, balanced sling load that resists the tendency to spin (Fig. 21). Over

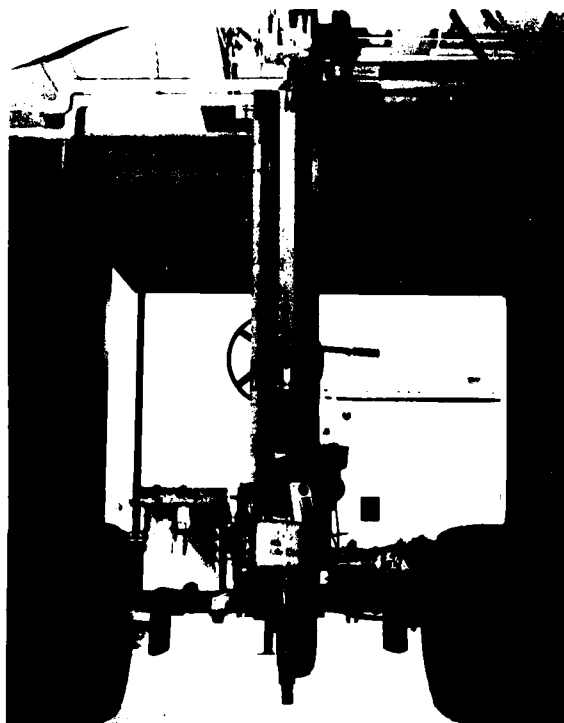
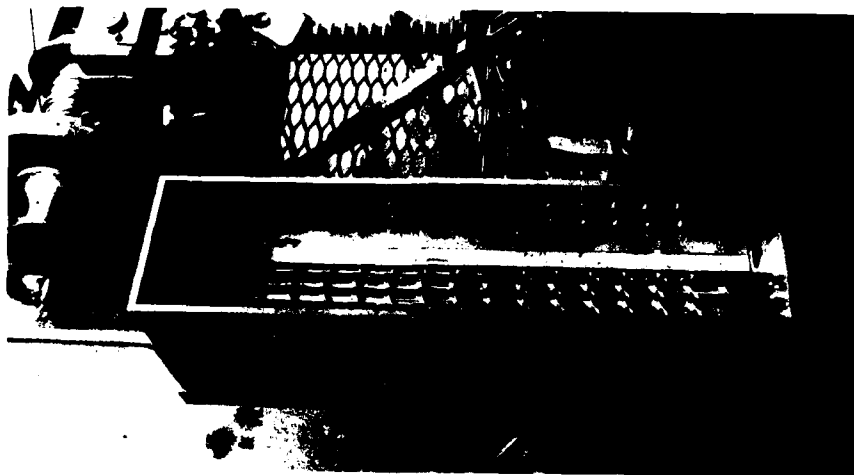
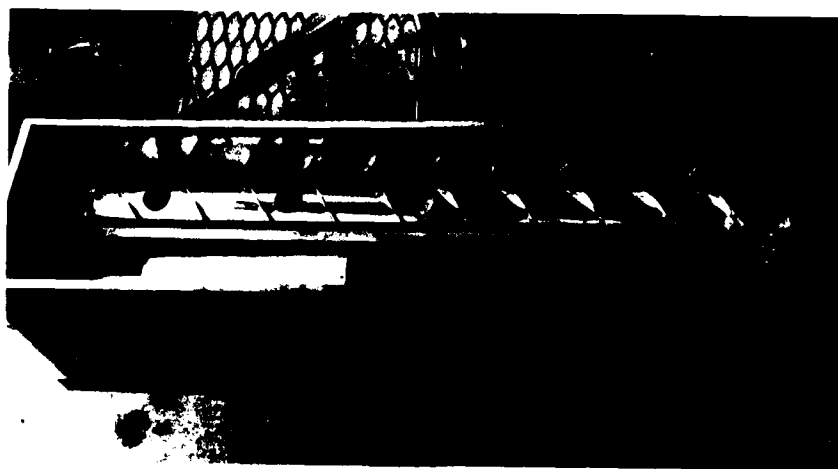


Figure 21. Prototype drill suspended from cable attached to inverted 'V' hook. In helicopter transport, it is a high density balanced load that resists swaying.



a. Bottom compartment containing 15 sections of continuous flight auger.



b. Middle tray containing 1-m-long coring auger and adapters.



c. Top tray containing tools, spare parts, and miscellaneous bolts, screws, etc.

Figure 20. Tool box.

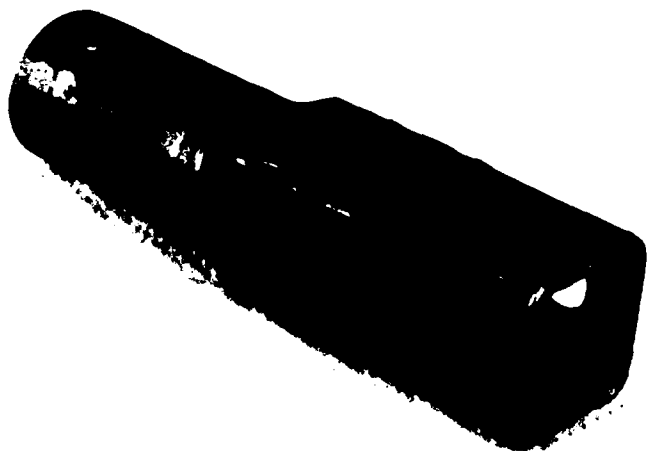


Figure 16. Round male to square female adapter for attaching rods to output shaft.



Figure 17. "Crown" adapter for attaching winch cable to drill string.

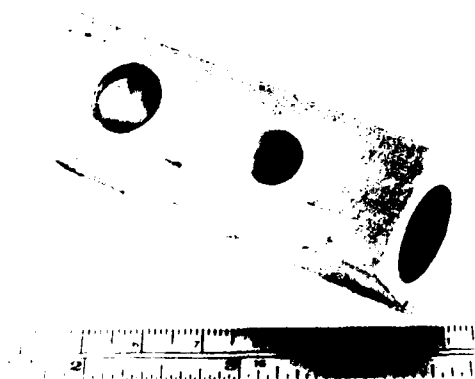


Figure 18. Square male to round female adapter for use of continuous flight auger (57 mm diam) on square rod.



Figure 19. Square male to round female adapter for use of square rod with the original head of the coring auger.

sorb water, is unaffected by low temperatures, and was readily available.

A series of adapters were fabricated to interchange the various augers, core barrels, drill rod, core and rod retrievers. The adapters are briefly described below:

1. An auger guide insert reduces the standard 150-mm guide for use with the continuous flight 57-mm-diam auger (Fig. 14a). A simplified head for the coring auger adapts directly to a square rod (Fig. 14b).

2. A 35-mm hex female to 32-mm round female adapter joins the output shaft of the Dig-R-

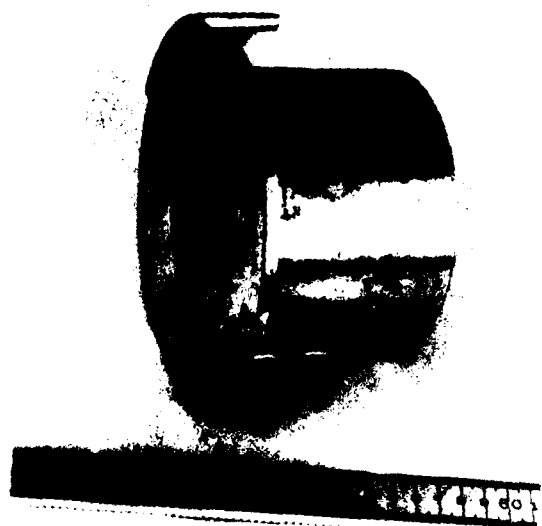
Mobile gear box to the coring auger head or extension rods (Fig. 15).

3. A round (32-mm-diam) male to square female adapter attaches the square rods to the output shaft of the gear box (Fig. 16).

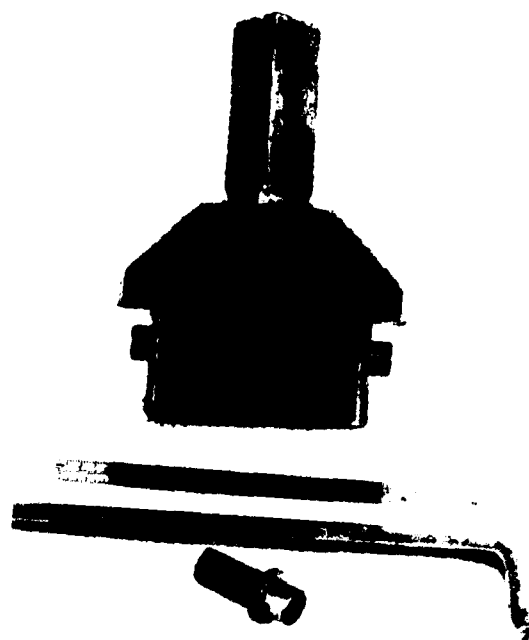
4. A "crown" adapter is used to attach the winch cable to the square rod (Fig. 17).

5. A square male to 17.5-mm round female adapter allows use of the 57.2-mm continuous flight augers with the square rod (Fig. 18).

6. A square male to round female adapter joins the square rod to the original CRREL coring auger head (Fig. 19).



a. Continuous flight, 57-mm-diam auger flight insert.



b. Simplified head.

Figure 14. Auger guide and simplified coring auger head.

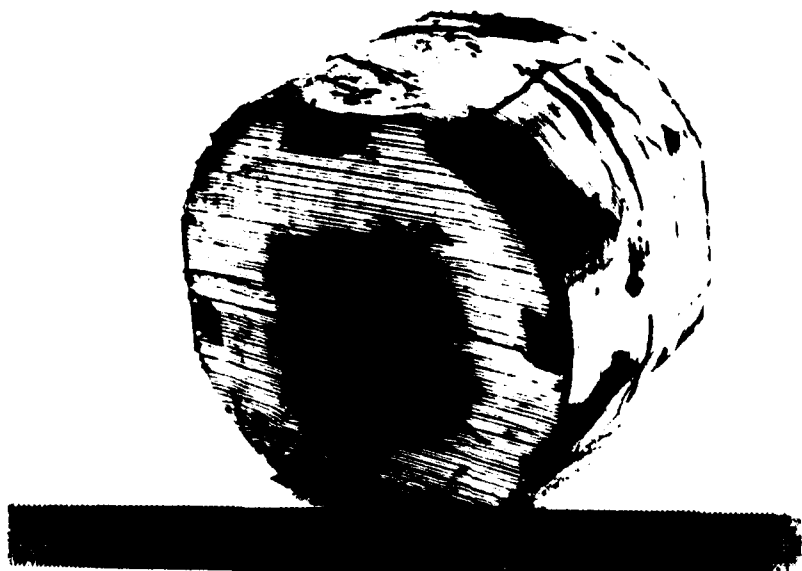


a. Hex end of adapter.



b. Female round end.

Figure 15. Adapter for use of CRREL coring auger on output shaft.



a. Fabricated of wood and tape in the field in 1981.



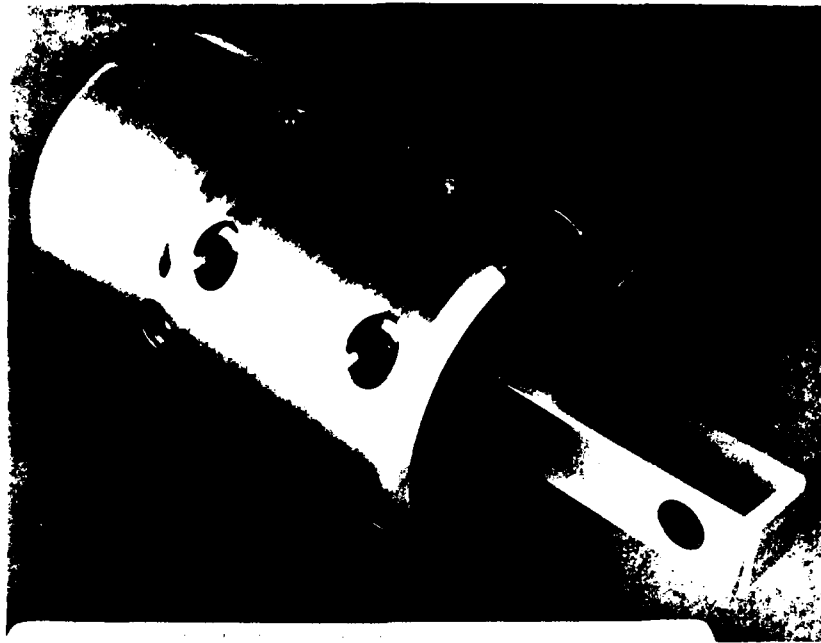
b. Stabilizer fabricated of Synthane tube at CRREL.

Figure 13. Rod stabilizer for controlling excessive wobble in drill string.

slip into the holes in the drill rod. We have not had to use this retriever to date for its designed purpose, but it has been used extensively for recovering core (as described below in *Typical Operating Procedures*).

Rod stabilizers are necessary to control the wobble of the drill string, particularly at depths greater than 10 m. Wobble is a result of the loose interconnections of the rods. We opted for loose connections to prevent thawed sediment from binding

rod connections and to ensure ease in reconnecting rods. Experimental stabilizers were initially whittled from wood timbers while in the field in 1981 (Fig. 13a). They were covered with fiber tape and dropped over each section of rod as the drill string was assembled. Because these stabilizers were found to effectively control the wobble, we fabricated stabilizers from Synthane tubes, epoxy resin and aluminum rod (Fig. 13b). Synthane was selected as a base material because it does not ab-



a. Side view with square female end for connection to drill rod.



b. Down-hole end with concave face and four internal spring pins that hold rod.

Figure 12. Rod retriever fabricated to retrieve a drill string that is accidentally dropped down a hole.

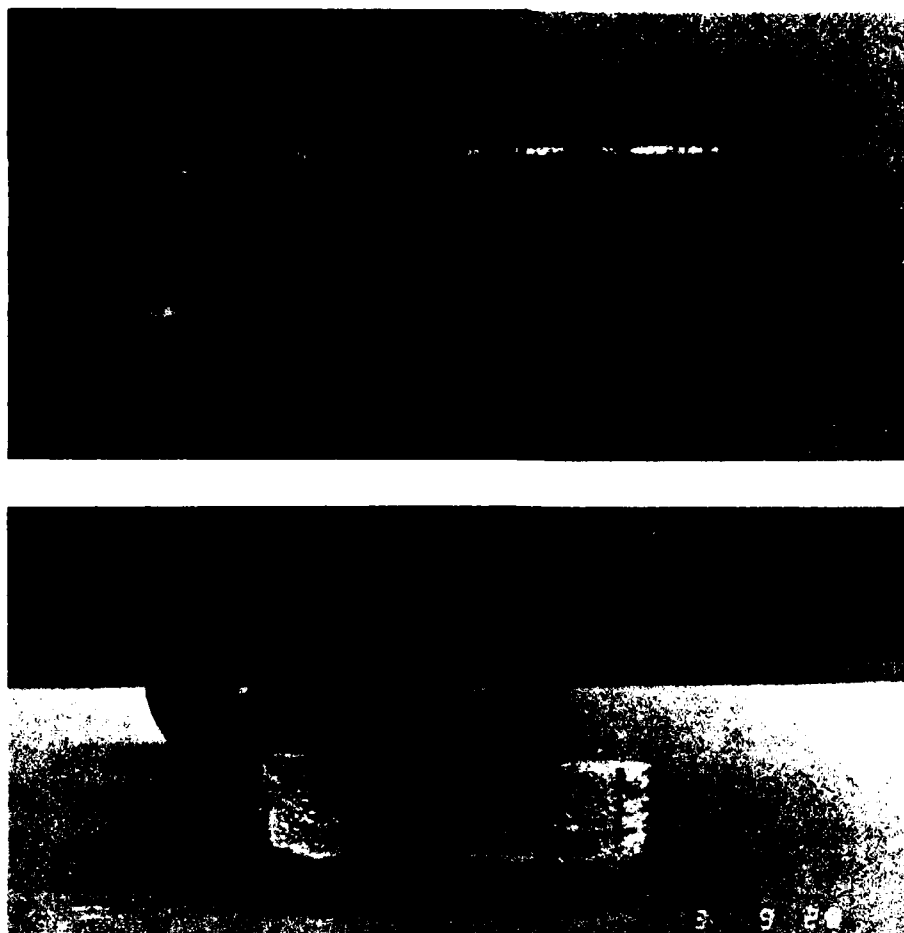


Figure 11. Core catcher of aluminum tube with internal spring clips to retain core sample. Head is removed to retrieve core from tube.

allow reverse rotation of the drill string. A third hole was drilled through the tube and the rod for use with a fabricated pin and plate system (described below). A total of 33 m of rod, consisting of 15 sections 2 m long, two sections 1 m long, and 2 sections 0.5 m long, were fabricated. To connect the drill rod directly to the coring auger a new head (designed by J. Rand) was fabricated. This simplified design eliminates binding of the internal mechanisms of the original head by thawed silts.

The components of the pin and plate system are shown in Figure 10. They are made from a 200-mm-square, 13-mm-thick aluminum plate with a 32-mm-wide and 100-mm-long slot cut to its center. The pin is a 200-mm-long, 13-mm-diam soft steel rod bent to form an L-shaped pin. When lowering or raising the rod, sections are disconnected by pushing the plate slot around the rod and inserting the pin through the hole in the rod (Fig. 10a). The drill string is then suspended from the plate

and pin, which rests upon either casing or timbers placed next to the drill hole (Fig. 10b). A handle was attached to the plate to prevent fingers from accidentally being caught beneath it as the drill string is raised or lowered.

A core catcher (Fig. 11) (designed by H. Ueda) is used to retrieve core from the bottom of a hole. The core catcher consists of an 80-mm-diam aluminum tube with four spring steel teeth. The teeth allow the core catcher to slip over the core. The teeth dig in as the catcher is raised. The head is removed and the core sample is pushed through the catcher for retrieval.

A rod retriever was designed and fabricated for use in the event that the drill string is accidentally dropped down the hole. The steel receiver has an outside diameter of 102 mm, and centering of the drill rod is automatic because of the concave shape (Fig. 12). Once it has been lowered into position on top of the rod, two of the four spring bolts can



a. Inserting pin in rod hole below the rod-to-rod connection and Hartwell pin.



b. Drill string suspended from pin and plate, which is resting on casing.

Figure 10. Fabricated pin and plate system for systematically adding or removing drill rod in deep holes.

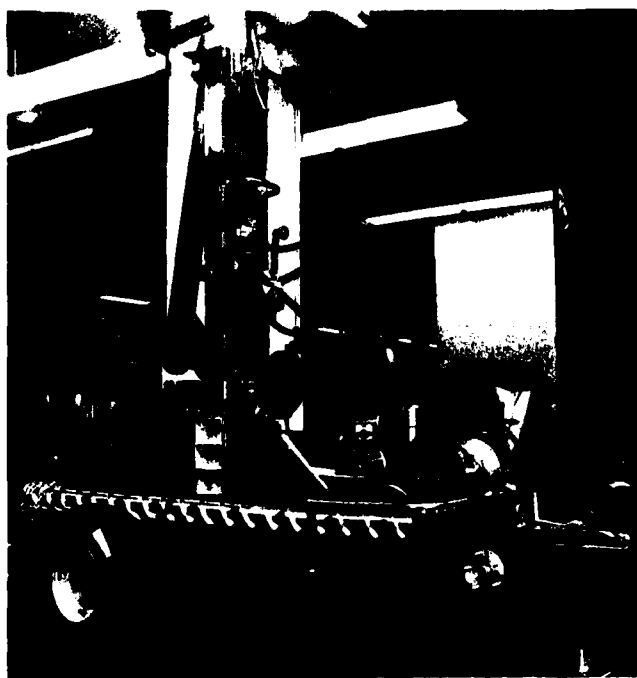


Figure 8. Drill with small tires mounted for towing on roads. Arrow locates inverted 'V' hook for sling transport by helicopter.

and installed to allow freedom of both hands during coring and retrieval operations. The brake pedal release mechanism is attached to the throttle/brake lever (Fig. 5). Enough slack is provided at the connections to allow for unobstructed leveling of the mast.

A gasoline-powered winch was bolted onto a frame that is welded to the drill platform and trailer tongue (Fig. 8). This winch was originally used to raise and lower the drill rod and core barrel, but was later replaced by a mast-mounted electric winch described below. The tubular bracing on the platform was reworked to 1) mount a locking plate for nesting the drill rod and core barrel (Fig. 8), 2) provide hand holds for maneuvering the drill in the field, and 3) allow for adequate space for the winch frame.

An electric winch is now mounted on the back side of the mast (Fig. 4). This location provides for a near-vertical pull and minimizes the lateral strain on the mast extension that was produced when using the gas winch. The electric winch is operated from a control box on the end of a 3-m-long cable. The winch has a constant speed in both forward and reverse drive and has a trigger dynamic brake that is automatically applied when the control button is released. This winch was selected primarily for the safety provided by the constant speed and braking system.

Drill accessories

Sections of drill rod were manufactured from square steel tubing with a square cold drawn rod (Fig. 6c). Sections of rod were shimmed and welded into one end of the square tubing so that equal portions of the solid rod were contained within the tube and protruded from it. Holes were drilled in both ends of the tube to interconnect the sections of rod by use of Hartwell pins (Fig. 9). These pins were selected because of their previous successful use with the standard CRREL ice coring auger (Ueda et al. 1975) and because they would



Figure 9. Hartwell pin.



Figure 6. Close-up of front end of drill set up on site in northern Alaska in 1981. Jack stands and extension arms (A) located on boards to prevent sinking into thawed soil. Upper part of hole has been augered and aluminum casing set (B) prior to coring operations. Square drill rod is on right side of drill platform in transport position (C).



Figure 7. Back end of drill with stock tires mounted on trailer tongue and gasoline-powered winch mounted on frame welded to the tongue and drill platform. In this position, the winch was used for raising or lowering the drill string and local movements. Locking plate (A) is used to hold drill rod and 1.5-m-long core barrel on drill platform.

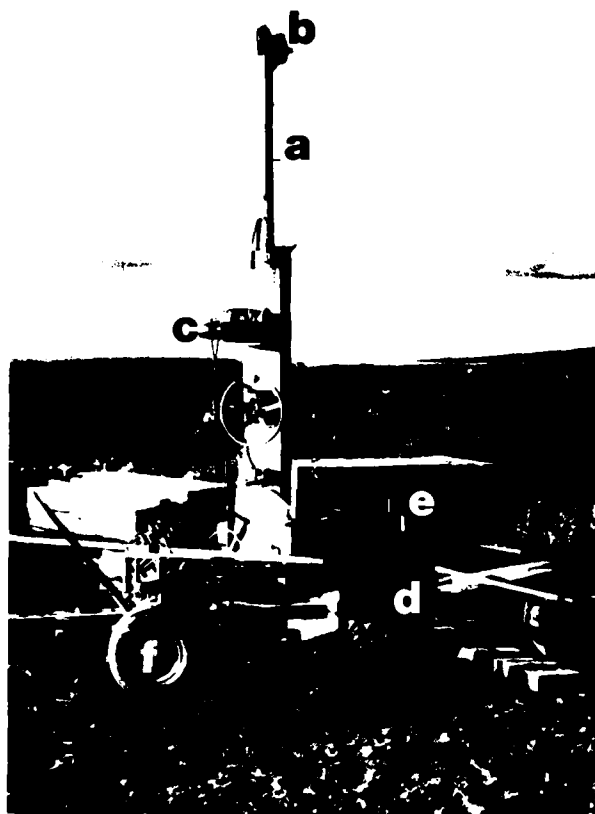


Figure 4. Prototype drill in 1983. Modifications to the model 550 base unit include a) mast extension, b) roller guide and winch cable, c) electric winch, d) balloon tires, e) jacks and mounts, and f) two-wheel trailer tongue.

a short safety chain is used to prevent it from accidentally falling (Fig. 4). The addition of the mast extension provides a vertical clearance of 3.5 m, enough to pull a 2-m section of drill rod with a 1.5-m core barrel attached.

Hand-operated, screw-type implement jacks are mounted on extension arms, which are bolted to the front of the drill platform (front refers to the side of the drill platform with the mast, motor and cradle) (Fig. 6). Each jack has a 0.38-m-travel and 900-kg capacity. A third jack with a 0.25-m travel and 900-kg capacity is mounted on the trailer tongue. These jacks are necessary to level the drill and stabilize it while it is operated.

Two bubble levels set at right angles to one another are mounted on the rear face of the mast to provide visual control when leveling with the jacks, as well as for monitoring the drill position during operation.

Two balloon tires are mounted directly to the

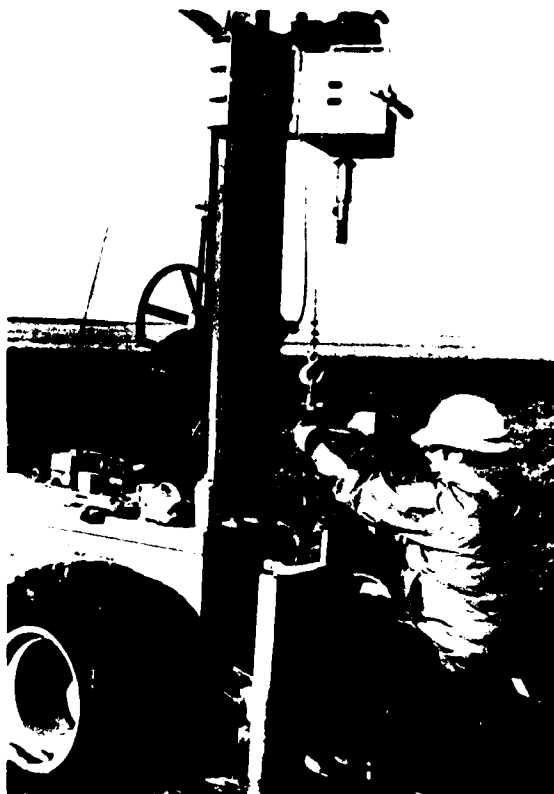


Figure 5. Close-up showing fabricated foot brake release mechanism, with the foot brake pedal (A) and upper loose connection (B) to allow vertical adjustment of mast. Mast extension is bolted to mast for transport (C).

existing hubs with adapter plates (Fig. 6). Both of the road tires are mounted to a fabricated hub and attached to the tongue jack stand (Fig. 7). For trailering over roads, the balloon tires must be removed and replaced with smaller road tires (Fig. 8) as the larger tires cannot be drawn at speeds over 50 km/hr. With four tires mounted, the drill produces a ground pressure of 1.8 gf/mm² (2.6 psi).

In addition, three skis were fabricated from 6.35-mm-thick aluminum channel to permit mobility over snow. Two of the skis bolt to the hubs replacing the balloon tires; the other, a pivotal ski, is inserted into a socket beneath the trailer tongue. With the three skis mounted, ground pressure is 0.91 gf/mm² (1.3 psi). An inverted V-shaped hook (Fig. 8) was welded at the top of the mast for attaching the drill to a choker and subsequent transport beneath a helicopter.

A brake release pedal (Fig. 5) was fabricated



c. Inserting pin in rod as drill string is progressively lengthened and lowered.



d. After completion of coring, motor and cradle are swung away and sections of drill rod progressively removed.



e. Core barrel at surface after pulling entire drill string.



f. Removing core barrel head for core sample retrieval.

Figure 23 (cont'd).

head of the core barrel and agitating the antifreeze with a stream of air. The introduction of an air compressor to this system is currently being evaluated.

The most routine problem we encountered was retrieving cores that did not break free from the hole bottom. This problem was commonly experienced in 1981 in frozen sediments with low ice content. Successful retrieval of a core sample depends upon wedging cuttings between the inner walls of the core barrel and the core sample. This binds the core in place and allows rotation to break the sample at the toe of the barrel. In ice this method works well; however, this method does not work in frozen sediments with low ice content because of their resistance to shearing. Thinking that the greater length of core within the barrel would effectively increase the shear stress applied to the base of the core, we tried first a 2-m- and subsequently a 1.5-m-long version of the CRREL coring auger. These core barrels did not retrieve core any better than the original barrels, primarily because the maximum speed of the drill motor (144 rpm) is insufficient to transport cuttings up the full length of the flights to the top of the core barrel. The cuttings instead filled the lower portion of the flights and they limited increase in sample length to only 0.1 to 0.2 m. Further work on increasing both the efficiency of core retrieval and the length of individual samples is continuing.

In order to retrieve core samples that do not break free, a method was developed that minimizes loss of sampling time. If the core barrel comes up without retaining the core, the drill rod is immediately reattached and a second, equally deep cut is made. If the core again does not break free, a third cut is made. (Three cuts are all that are possible—this is the full length of the interior of a 1-m-long barrel.) If a core is again not retained in the barrel, the core barrel is removed and a 2-m length of rod is attached to the end of the winch cable and lowered down the hole. When the top of the core is reached, as can be determined by observing a slackening of the cable, another 0.3 m of cable is played out, the rod is lifted by hand about 0.3 m above the core, and then the rod is allowed to free-fall. (If the core breaks, the cable will be taut.) Then the winch is reeled in, the rod is removed and the rod retriever attached (Fig. 12). In the rod retriever, the square to female round adapter is inserted (Fig. 19) and the core catcher is attached to the female round (Fig. 11). The hole is descended to the bottom. Again 0.3 m of cable is played out, and the core catcher is lifted, and allowed to free-fall. The catcher should drop over

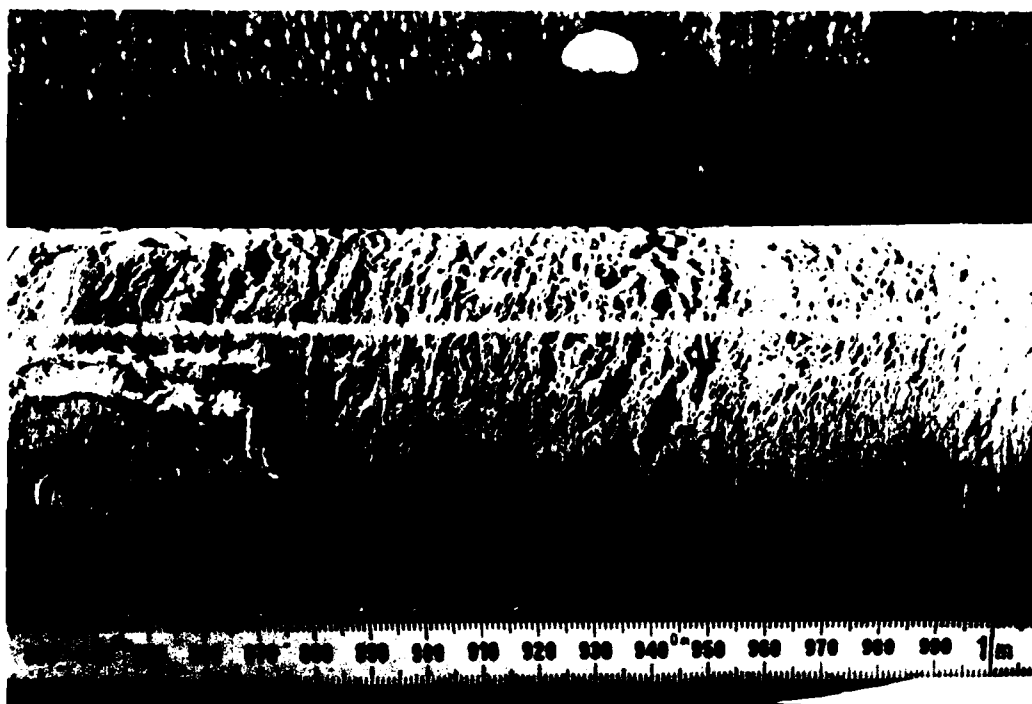
the end of the core. This method has proven successful and cores have been retrieved at depths of 20 m. Cores are only slightly damaged (e.g. with chipped edges) when using this method.

CORE QUALITY AND COMPARISON

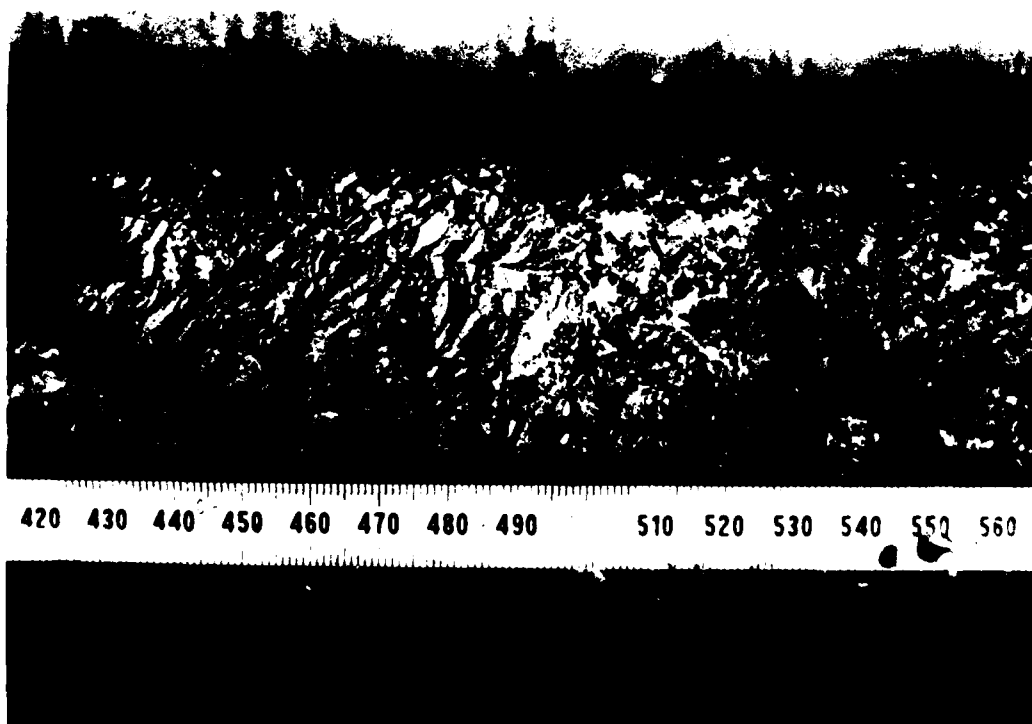
The most important feature of this drill system is the quality of the core sample produced. This quality is produced by controlling the penetration rate as physical conditions and material composition change. The operator needs to gain experience in order to judge the progress of the cutters and respond to changes in the controlling factors by adjusting the speed or depth of cut. For example, penetration rates that are too aggressive can produce fractured and broken cores, while rates that are too slow may cause melting or balling up of the cuttings and produce refreezing problems. Incorrect positioning of the cutters will likewise produce an irregular and scored surface on the core sample. In general, maintaining a consistent depth of cut per revolution as governed by material and physical conditions will produce undisturbed core samples from a variety of fine-grained sediments (Fig. 24).

Cores of frozen sediments containing a range of ice from 10 to 90% by volume and pure ground ice obtained with the CRREL coring auger are internally unaltered. Thin sections representative of cores of frozen sediments and sediment-laden ice photographed under cross-polarized light illustrate the quality of the core samples (Fig. 25). Each core typically has only a narrow annulus of disturbed material on its outer 1 to 2 mm. Breaks in the core may sometimes result along planes of weakness within the frozen materials, but adjacent to these breaks the ice is basically unaltered. For comparison, samples obtained in 1979 with a modified Shelby tube (Lawson and Brockett 1980) at the same field sites are shown in Figure 26. This comparison is important because a modified Shelby tube similar to the one used by us in 1979 is commonly employed in obtaining core samples for geotechnical siting studies and laboratory testing of the in-situ engineering properties of frozen ground. These cores are often assumed to be undisturbed.

The cores from the modified Shelby tube, particularly those of massive ice or ice-rich sediments, often have only a small part of the interior of the core that is not disturbed and recrystallized (Fig. 26). In some samples of ice we have examined, only about a 10-mm-diameter cylinder of material in

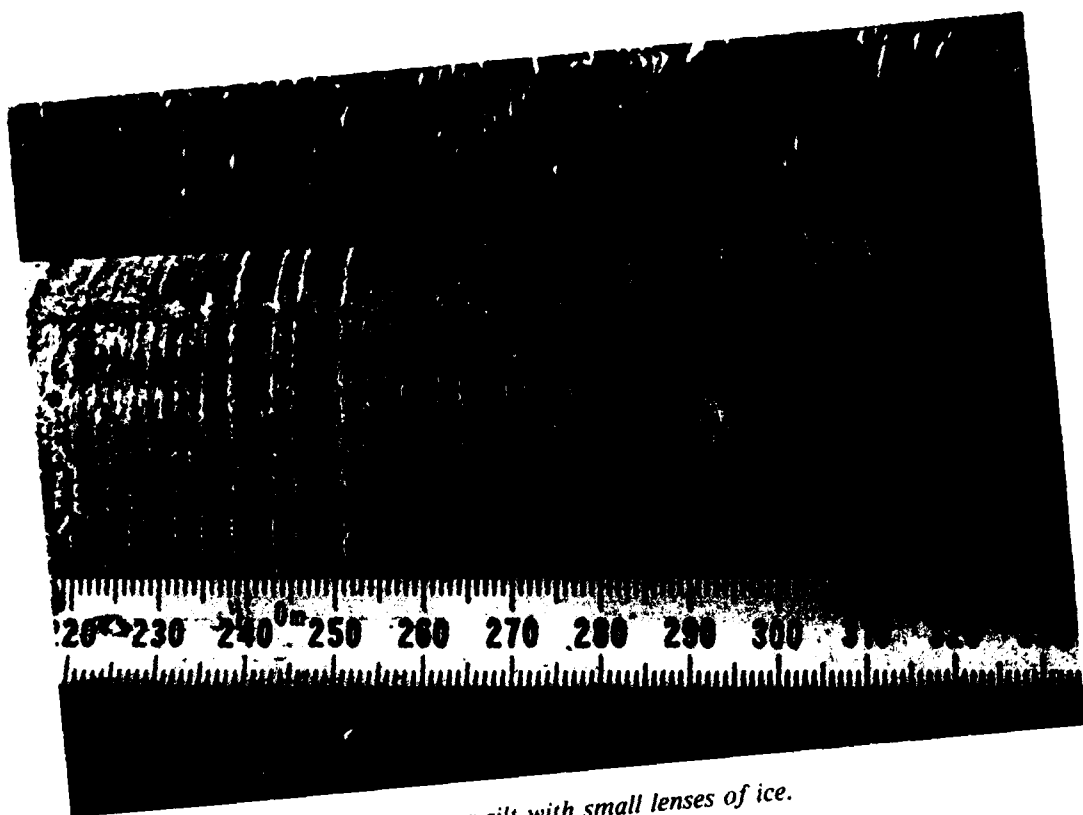


a. Segregated ice in silt.

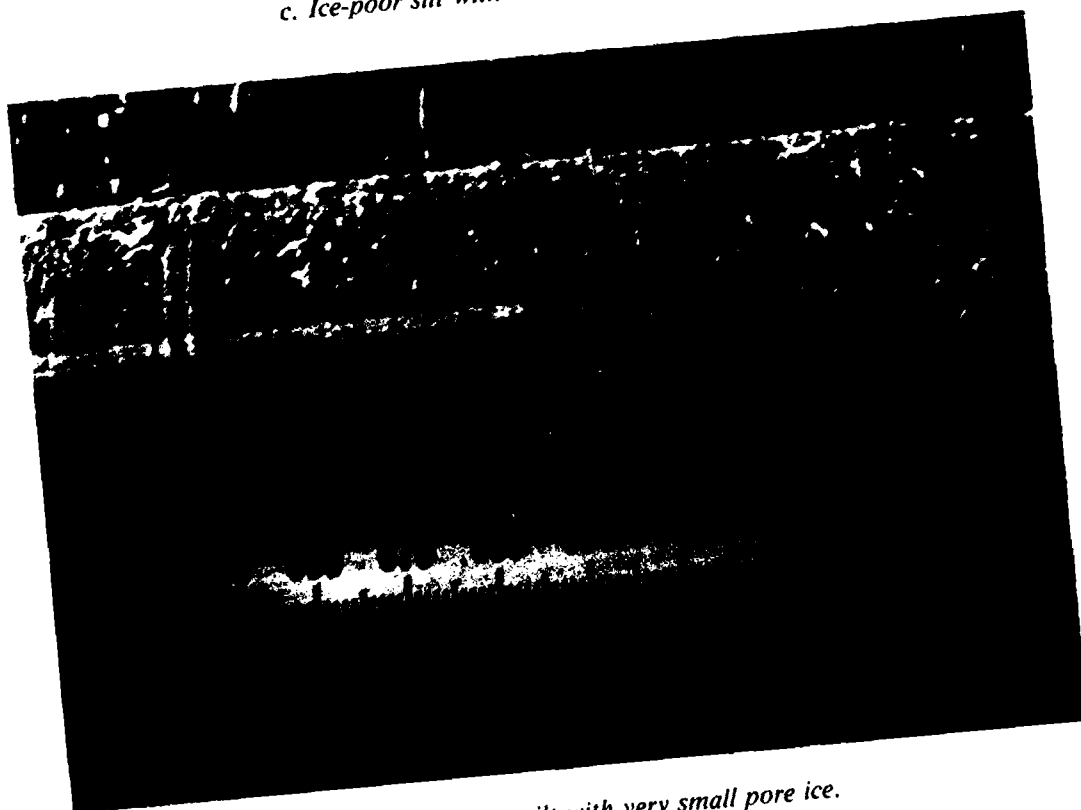


b. Ice-rich clayey silt.

Figure 24. Examples of core samples of different grain size and ice content.



c. Ice-poor silt with small lenses of ice.



d. Ice-poor silt with very small pore ice.

Figure 24 (cont'd). Examples of core samples of different grain size and ice content.



e. Ice lenses of 2- to 4-cm thickness in organic-rich silt.



f. Thin veins of ice in organic clay silt of frozen active layer.

Figure 24 (cont'd).

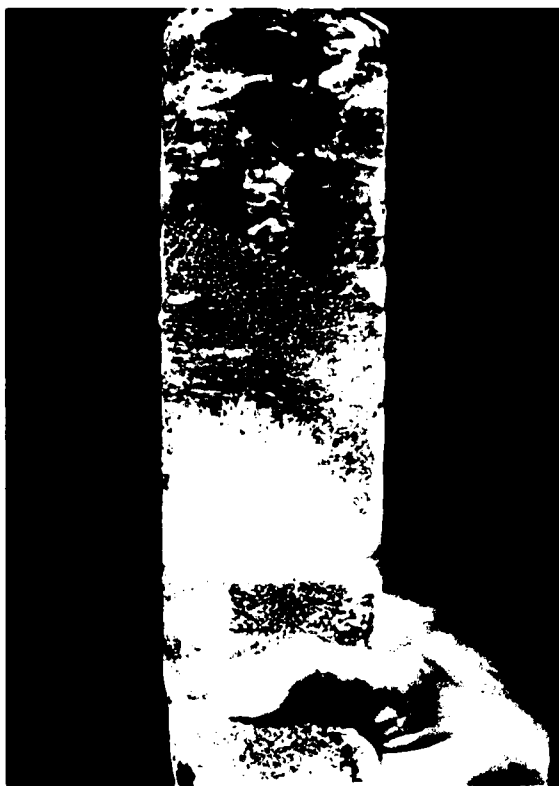


g. Tip of ice wedge in sand with pore ice.



h. Wedge ice with foliated structure.

Figure 24 (cont'd). Examples of core samples of different grain size and ice content.



i. Bubble-rich pingo ice.



j. Massive ice lens with suspended organic layer.

Figure 24 (cont'd).



a. Ice-wedge ice.

Figure 25. Thin sections under cross polarized light of representative cores obtained using the CRREI coring auger and drill.



b. Ice veins in silt.



c. Massive ground ice, with variable grain size, infilled cracks and recrystallized natural fracture zones (same ice as Fig. 26c).

Figure 25 (cont'd). Thin sections under cross polarized light of representative cores obtained using the CRREL coring auger and drill.

the core's center remains unaltered (Fig. 26). In ice-rich sediments, veins and lenses of ice are crushed and refrozen, and in some, the sediments are similarly modified with individual grains reoriented. In addition, breaks in the cores were common and, adjacent to these breaks (including those at the core base caused by snapping the core

samples off for retrieval), the ice and frozen sediments are also disturbed (Fig. 26). Clearly, the results of tests on those cores sampled with the modified Shelby tube would not be representative of the in-situ properties of the perennially frozen materials, whereas those sampled with the CRREL coring auger would be.



a. Ice-wedge ice, with only central, upper part of core appearing to be unaltered.



b. Ice-rich clayey silt, with individual ice veins and lenses (arrows) exhibiting crushing and refreezing.



c. Greatly disturbed massive ice, including altered ice along drilling-induced fractures. Only core center is undisturbed.

Figure 26. Thin sections under cross-polarized light of representative cores obtained using a modified Shelby tube and Mayhew 200 rotary drill rig.

EFFECTS OF MATERIAL PROPERTIES, WEATHER AND WATER

We have observed certain effects of the frozen sediment's grain size, ice content and temperature on the depth of core sampling. Clean ice or sediment-rich ice were the easiest materials to core sample. Similarly, ice-rich silt and ice-rich sand were easily cored and were the materials within which we attained the greatest hole depths. Sandy sediments dulled the cutters more rapidly than silty sediment, although ice-poor sand was found to be operationally easy to core in comparison to ice-poor silt or clay. The noncohesive, granular nature of the cuttings appears to be the reason for this difference.

Difficulty was experienced in relatively dry frozen silt or silty clay. In these materials, cuttings became plastic, balled up, jammed between the hole wall and core barrel and caused the barrel to stick in the hole. The barrel often froze in place as soon as rotation ceased. Although we have cored to depths of 15 m in these materials, excessive strains on the drill were experienced. Dry frozen silts or clays at temperatures above -5°C should be considered a material limitation of the prototype system.

Casing must be used in near-surface highly organic-rich materials or peat that have been partly thawed or contain a relatively large volume of unfrozen water. Water in these materials seeps into the hole, where it freezes and reduces the hole's diameter, thereby preventing the core barrel from being removed.

The coring auger cannot routinely cut cores in sediments with a grain-size larger than coarse sand. When gravel is encountered, damage to one or both carbide cutters is probable. The carbide cutters are capable, however, of cutting through *calcareous* gravel-rich sand. We have also augered through surface gravels to a depth of 2.4 m, both frozen and unfrozen. Augering frozen gravel is not recommended because of the adverse effects on the drill.

The temperature of the permafrost is an important factor that can vary considerably. For example, material with a temperature below about -3°C produced few problems if the active layer was frozen and air temperatures were below freezing. In contrast, coring of warm permafrost (-1 to -0.5°C) under cold winter ambient temperatures caused problems because the sediment near the surface was colder than the samples extracted from a greater depth. As soon as the warmer cuttings on the barrel flights came in contact with the colder

hole wall near the surface, the barrel froze in place.

In addition, the previous stress history of the materials, particularly of ice, is important. Layers that have apparently been affected by geologic stresses or recrystallization may act as planes of weakness and break into small sections or fragments during coring.

Finally, in permafrost at temperatures of -1° to -1.5°C , thaw zones were encountered. Slurries of supersaturated fine-grained material would flow from these zones into the holes, resulting in freeze-in of the core barrel and abandonment of that hole.

DEPTH AND HOLE COMPLETION TIME

Thus far, we have continuously core sampled a total of 168 holes from which about 1092 m of core samples have been collected for research projects. In addition, two open holes to depths of 12 m have been augered with the 57-mm augers.

Materials core sampled have ranged from clay- to coarse-sand-size, with ice volumes ranging from 10 to 100%. Large bodies of massive ground ice have also been continuously cored, as have frozen, organic-rich materials and peat.

The time necessary to complete each hole is governed by the material type sampled, condition of the barrel, proficiency of the operators and core retrieval efficiency. Because these factors vary from hole to hole, it is not possible to accurately define the rate at which a given length of core can be sampled. The first 10 m of core is typically extracted in less than 5 hours. Sampling the 10- to 20-m depth increment will require additional time because of the increase in time needed to lower and raise the drill string. We feel that the ability to acquire 1-m-long core samples will be forthcoming and the time to continuously sample to depths of approximately 20 m reduced to less than one day.

SUMMARY

A portable and lightweight drill system that can auger and core-sample perennially frozen ground of clay- to coarse sand-size has been developed through field use. Basically unaltered core samples obtained with a modified CRREL coring auger are useful for both chemical and physical analyses. The base unit for this drill is inexpensive and, with total modifications described in this report, esti-

mated to cost about \$10,000. It is designed for safe use by persons with little or no experience in drilling operations, although as experience with the drill and CRREL coring auger is gained, the number of high quality core samples recovered will increase. Off-road transport can be accomplished with light plane, helicopter, tracked vehicle or snow vehicle, and the drill can be towed over roads. With the use of a winch, the drill is locally self-mobile.

Continuous samples have been acquired to a depth of 22.5 m and we anticipate being able to reach depths around 30 m in ice-rich sediments. Various external factors that affect the capabilities of the drill include the weather, local topography, sediment grain size, ice content of the sediment, ground temperatures and presence of surface and ground water. The ideal materials for continuously coring with this drill and coring auger are ice-rich silt and ground ice, but high quality cores can be obtained of silty clay to coarse sand-size sediment containing varying amounts of ice. Development and refinement of the drill system are continuing.

LITERATURE CITED

- Davis, R.M. and F.F. Kitze** (1967) Soil sampling and drilling near Fairbanks, Alaska: Equipment and procedures. USA Cold Regions Research and Engineering Laboratory, CRREL Technical Report 191. AD 816654.
- Esch, D.C.** (1982) Portable powered probe for permafrost. State of Alaska, Department of Transportation and Public Facilities, Fairbanks, Report No. FHWA-AK-RD-83-12, 13 pp.
- Lawson, D.E.** (1982) Long-term modifications of perennially frozen sediment and terrain at East Oumalik, northern Alaska. CRREL Report 82-36, 30 pp.
- Lawson, D. and B. Brockett** (1980) Drilling and coring of frozen ground in northern Alaska, spring 1979. CRREL Special Report 80-12, 14 pp. ADA 084277.
- Lawson, D.E., J. Brown, K.R. Everett, A.W. Johnson, V. Komárková, B.M. Murray, D.M. Murray and P.J. Webber** (1978) Tundra disturbances and recovery following the 1949 exploratory drilling, Fish Creek, northern Alaska. CRREL Report 78-28, 112 pp. ADA 065192.
- Lawson, D.E. and J. Brown** (1979) Human-induced thermokarst at old drill sites in northern Alaska. *The Northern Engineer*, 10(2): 16-23.
- Mellor, M. and P. Sellmann** (1975) General considerations for drill system design. CRREL Technical Report 264. ADA 012646.
- Nixon, M.** (1977) ATV-Drill performance: A case study, Fort Simpson, District of Mackenzie. Scientific and Technical Notes. In *Current Research*, Part B. Geological Survey of Canada, Paper 78-1B, pp. 212-214.
- Sellmann, P. and J. Brown** (1965) Coring of frozen ground, Barrow, Alaska. Spring 1964. CRREL Special Report 81. AD 472341.
- Sellmann, P.V., R.I. Lewellen, H.T. Ueda, E. Chamberlain and S.E. Blouin** (1976) Operational report: 1976 CRREL-USGS subsea permafrost program, Beaufort Sea, Alaska. CRREL Special Report 76-12. ADA 032440.
- Ueda, H., P. Sellmann and G. Abele** (1975) USA CRREL snow and ice testing equipment. CRREL Special Report 146, 14 pp. ADA 01512.

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Prototype drill for core sampling fine-grained perennially frozen ground / by Bruce E. Brockett and Daniel E. Lawson. Hanover, N.H.: Cold Regions Research and Engineering Laboratory; Springfield, Va.: available from National Technical Information Service, 1985.

v, 34 p., illus.; 28 cm. (CRREL Report 85-1.)

Bibliography: p. 29.

1. Arctic regions. 2. Augers. 3. Core sampling. 4. Coring auger. 5. Drilling machines. 6. Fine-grained materials. 7. Frozen ground sampling. 8. Ground ice. 9. Permafrost. I. Lawson, Daniel E. II. United States. Army. Corps of Engineers. III. Cold Regions Research and Engineering Laboratory, Hanover, N.H. IV. Series: CRREL Report 85-1.

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